All-Normal Dispersion Photonic Crystal Fiber for Coherent Supercontinuum Generation

L. E. Hooper, P. J. Mosley, A. C. Muir, W. J. Wadsworth, J. C. Knight
Centre for Photonics and Photonic Materials, Department of Physics, University of Bath, Bath, BA2 7AY, UK
L.E.Hooper@bath.ac.uk

Abstract: We describe supercontinuum generation in a short photonic crystal fiber with all-normal group velocity dispersion. We observe a 200 nm broad self phase modulation spectrum, which is expected to have high temporal coherence.

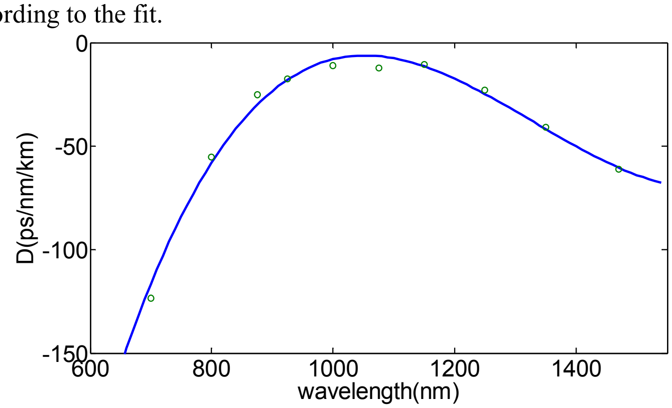
OCIS codes: (190.4370) Nonlinear optics, fibres (060.5295) Photonic crystal fibers

1. Introduction

Broadband light sources are important for applications such as nonlinear microscopy, optical coherence tomography, frequency metrology, and ultra short pulse compression. Photonic crystal fibers (PCF) are useful for supercontinuum generation due to the ability to engineer their dispersion and nonlinear properties [1]. State of the art supercontinuum PCFs are usually optimized to produce maximum spectral bandwidth. However, the dominant spectral broadening mechanisms in these types of fibers are soliton fission, which is sensitive to shot to shot fluctuations, and modulation instability, which is seeded from noise [2], resulting in phase noise and unstable amplitude across the spectrum. Noise can be reduced by suppressing soliton fission – either by careful choice of input pulse parameters, or by engineering the fiber group-velocity dispersion (GVD) such that it is always normal and thus prohibits the formation of solitons. Here we present a fiber which has been designed with all-normal dispersion to generate supercontinuum by self phase modulation, an intrinsically low-noise process.

2. Normal Dispersion Fiber

A PCF was designed with GVD which is normal at all wavelengths, and low around the pump at 1064 nm. It was also designed to have near-zero dispersion slope at the pump wavelength. Fiber parameters were predicted by modeling using empirical relations [3]. The final fiber consists of a solid core with a cladding containing 8 rings of air-holes, with a pitch of 1.65 µm and a hole diameter to pitch ratio of 0.32. The measured GVD and a scanning electron microscope image of the fiber cross section are shown in Fig. 1. The points show the numerical derivative of two-point differences in group delay, and the curve shows the derivative of a 4^{th} order polynomial fit to the group delay. The dispersion at 1060 nm is -6 ps/nm/km, according to the fit.



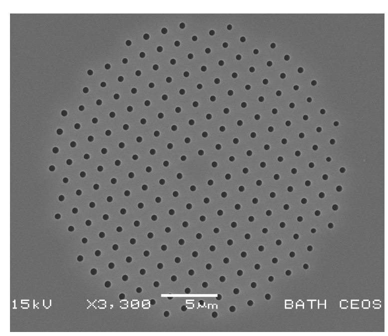


Fig. 1. Measured group velocity dispersion *D* of the normal dispersion fiber, and scanning electron microscope image of fiber cross-section. Dispersion measurements were carried out using a white light supercontinuum source pumped at 1064 nm, and hence there is less accuracy and increased scatter in the data near this wavelength.

CTuX4.pdf

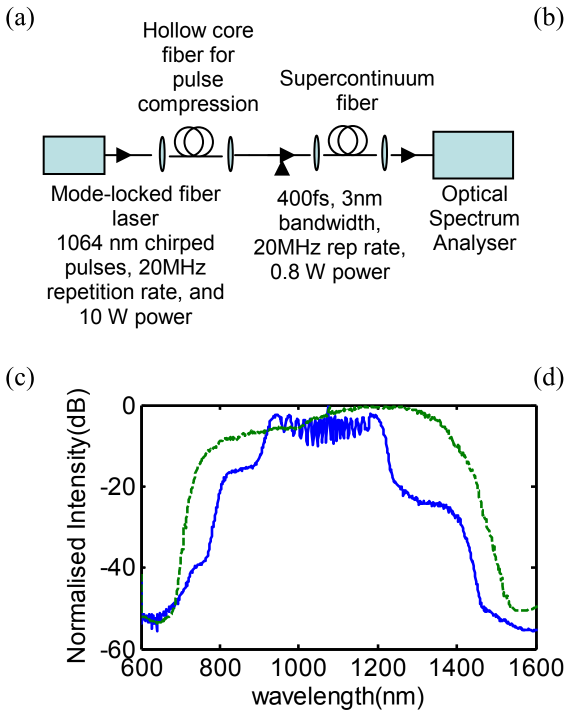


Fig. 2. (a) Schematic diagram of the experimental set up for measurement of the supercontinuum spectrum, (b) Supercontinuum generated in 5 cm normal dispersion fiber (solid blue line), pure self phase modulation spectrum in 5 cm fiber predicted by modeling (dispersion assumed to be zero)(dashed green line), (c) spectrum in fibre after 5 cm (solid blue line) and after 1 m (dotted green line), (d) spectrum from 5 cm conventional single mode fiber (Nufern 980HP) (dotted line), for comparison, all with same input pulse conditions.

Fig. 2(a) shows the experimental set up used to measure the supercontinuum generation in the normal dispersion PCF and other fibers for comparison. A fiber laser (Fianium Ltd.) emits chirped pulses centred at 1064 nm with average power 10 W and a 20 MHz repetition rate. These are launched into a hollow core fiber which compresses the pulses and yields solitons of 400 fs duration, with a central wavelength ~ 1075 nm and 0.8 W average power. After spectral filtering, the transform-limited pulses are launched into the fiber being tested. Output spectra are measured using an optical spectrum analyzer. The results of these experiments are shown in Fig. 2(b)-(d). The supercontinuum spectrum after 5 cm of normal dispersion fiber (Fig. 2(b)) is compared with that from 5 cm of conventional single mode fiber (*Nufern 980HP*, Fig 2(d)) with the same input pulse conditions. Both fibers generate spectra which are characteristic of self phase modulation, with that from the normal dispersion PCF being around three times broader and is more symmetric when using the same input pulse parameters, due to its higher nonlinearity and lower dispersion and dispersion slope. Also plotted in Fig. 2(b) is the predicted spectrum from modeling, assuming only self phase modulation and neglecting dispersion over the 5 cm length. The measured spectrum agrees very well with this modeled spectrum, confirming that self phase modulation is dominant in spectral broadening and that dispersion is low enough to be ignored for short fiber lengths. Fig. 2(c) shows that a bandwidth of ~800 nm can be achieved using 1 metre of normal dispersion PCF.

As the supercontinuum in 5 cm normal dispersion PCF is dominated by self phase modulation, it has a high degree of coherence and is therefore compressible. We plan to investigate this in future work. Also, similar fibre properties can be designed to operate at 800 nm wavelength, in order to be compatible with Ti:Sapphire laser systems.

This work was supported by the European Commission FP7 projects "CARS Explorer" (Grant HEALTH-F5-2008-2002880) and "nEUROPt" (Grant HEALTH-F5-2008-201076)

References

[1] Knight, J. C., "Photonic crystal fibers" Nature **424**, 847-851 (2003)
[2] Dudley, J. M. Genty, G., and Coen, S., "Supercontinuum generation in photonic crystal fiber" Rev.Mod. Phys **78**, 1135-1184 (2006)
[3] Saitoh, K. and Koshiba, M., "Empirical relations for simple design of photonic crystal fibers", Optics Express **13**, 267-274 (2005)